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Current Opinion in Environmental Sustainability

The potential of agroforestry in the provision of sustainable woodfuel in sub-Saharan Africa

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Woodfuel plays a critical role in energy provision in sub-Saharan Africa (SSA), and is predicted to remain dominant within the energy portfolio of the population in the coming decades. Although current inefficient technologies of production and consumption are associated with negative socio-economic and environmental outcomes, projected charcoal intensive pathways along with urbanization may further accelerate pressures on tree covers. This paper reviews the status of the woodfuel sector in SSA, and estimates the magnitude of impacts of increasing wood demand for charcoal production on tree cover, which will be obviously unsustainable under business-as-usual scenarios. Agroforestry, if widely adopted as an integrated strategy together with improved kilns and stoves, can have a significant impact to reduce wood harvest pressures in forests through sustainably supplying trees on farm. A systematic approach is required to promote multi-purpose agroforestry systems compatible with farmers' needs under local farming systems and current dryland socio-economic contexts.

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Current Opinion in Environmental Sustainability 2014, **6**:138–147

This review comes from a themed issue on **Sustainability challenges**

Edited by **Cheikh Mbow, Henry Neufeldt, Peter Akong Minang, Eike Luedeling** and **Godwin Kowero**

For a complete overview see the Issue and the Editorial

Received 08 June 2013; Accepted 17 December 2013

Available online 15th January 2014

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http://dx.doi.org/10.1016/j.cosust.2013.12.003

Introduction

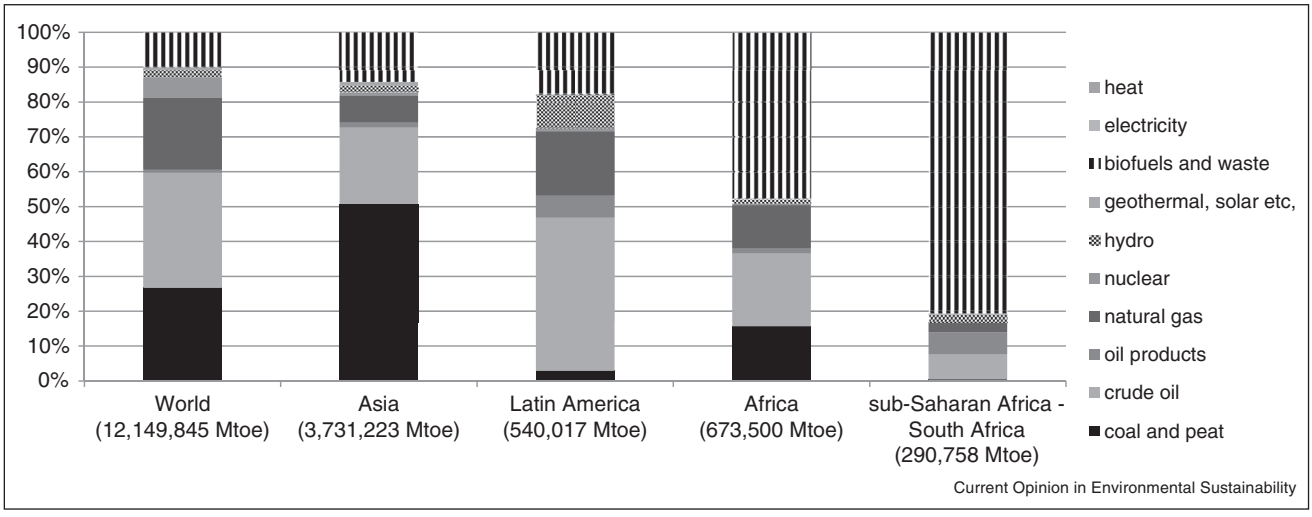
Although solid biomass accounts for only ~10% of primary energy supply globally, woodfuels continue to have a crucial and sometimes dominant role in energy provision in the developing world. Woodfuels account for >80% of primary energy supply in sub-Saharan Africa (SSA),[a] where >90% of the population rely on firewood and charcoal for energy, especially for cooking (Figure 1) [1,2•]. Indeed, SSA had the world's highest regional per capita woodfuel consumption in 2011 at an average of 0.69 m^3/year, compared with a global average of 0.27 m^3/year (Figure 2).

Although woodfuels dominate in the SSA region, the technologies of production and consumption are generally rudimentary and inefficient in wood use, leading to negative health, socio-economic, and the environmental outcomes [3•]. Indoor pollution caused by woodfuels burnt in inefficient stoves in badly ventilated cooking areas is a major cause of mortality from respiratory infections, with women and children suffering most, thus often labeled as the 'killer in the kitchen' [4••,5,6,7]. The scarcity of appropriate energy sources has led poor households to spend considerable time in woodfuel collection, time that otherwise could have been spent on more productive activities [8]. Lack of ready availability of other energy sources has also led to the burning of cow dung and/or crop residues that would be better used as fertilizers to support food production [9], to the burning of wood from tree species that were traditionally avoided because of their more harmful smoke [10], to the use of more polluting alternative fuels such as plastic [11] and to the giving up of cooking food properly altogether. Wide dependence on woodfuels harvested from forests and woodlands could significantly deplete these resources in SSA [2•,12].

Global policy debates on energy supply have mostly ignored woodfuels, but instead emphasized the need for the poor to gain access to 'modern' energy sources such as kerosene, liquefied petroleum gas (LPG) and electricity [13]. The reality is, however, that modern energy sources are unlikely to provide primary household energy needs for most of the poor in SSA for some decades yet, due to the fiscally unsustainable magnitude of the subsidies and infrastructure required to do so, and households' low incomes for fuel purchases [14,15•]. In

[a] In this paper, sub-Saharan Africa excludes South Africa, which for the region has an exceptionally high electrification rate. The following 42 countries in sub-Saharan Africa are covered: Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Central African Republic, Chad, Congo, Côte d'Ivoire, Democratic Republic of the Congo, Djibouti, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Malawi, Mali, Mauritania, Mozambique, Namibia, Niger, Nigeria, Rwanda, Senegal, Sierra Leone, Somalia, Sudan (former), Swaziland, Togo, Uganda, United Republic of Tanzania, Zambia, Zimbabwe.

Figure 1



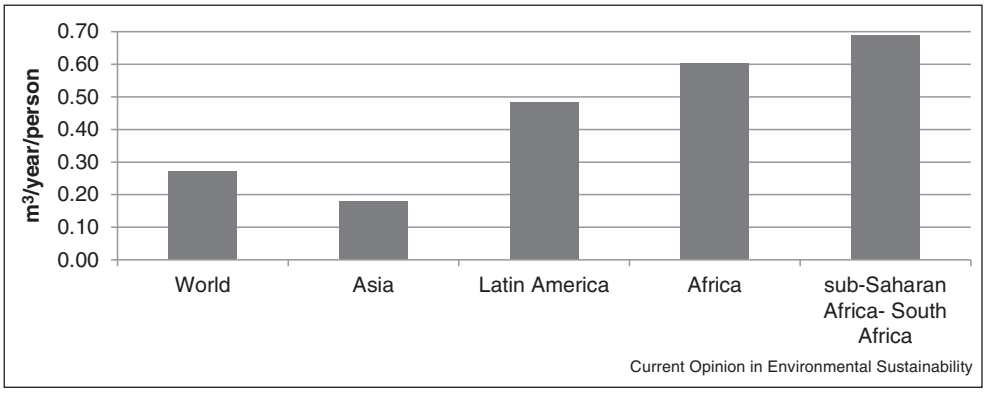
Regional comparison of contributions of different primary sources to energy supply in 2009.
Source: IEA Statistics (www.iea.org/stats/).

the coming twenty years or more, charcoal will be consumed by a wide range of socio-economic groups in SSA while firewood will remain important for the poorest who cannot afford charcoal [16••,17••]. Current trends may accelerate forest degradation [18].

Efforts to provide energy for all communities in SSA, at an acceptable environmental cost, mean little without recognizing the reality of the continued importance of woodfuels, and should support reform of the sector to make it more efficient and sustainable, rather than just discounting it in future planning [16••,17••]. Woodfuel production in agroforestry systems may provide a more sustainable alternative to collection from natural forest and woodlands, and could provide multiple benefits for smallholders, while limiting land degradation and deforestation, with possible net sequestration, raising incomes, and improving health and nutrition [18,19].

Few harmonized estimates exist on the future of the woodfuel sector in SSA to guide policy debates. The current review addresses how the woodfuel sector in SSA can meet the energy demands of the poor who will not benefit from modern energy supplies in the near future in ways that are sustainable and avoid serious health risks, and assesses the potential role of agroforestry. First, the current status of the woodfuel sector in the region with a particular focus on charcoal is considered, followed by the review on past unsuccessful approaches to promote woodfuel supply. Then a simple model to project wood demand for charcoal production and its impacts on tree cover under scenarios of the

Figure 2



Regional comparison of per capita woodfuel consumption in 2011.
Source: FAOSTAT (http://faostat3.fao.org/).

adoption and non-adoption of appropriate practices is presented. The review concludes by calling for a systematic approach for supply management interventions, and outlining critical information gaps for guiding policies and promoting wider-scale adoption of improved methods.

The woodfuel sector in SSA

The status

In SSA, firewood is widely used in rural areas [17••] and sometimes in cities [20], although it is often regarded as an inferior energy source for use by the poor [17••]. Firewood is also used by industries and estates such as tea, coffee and tobacco [20]. The use of charcoal is preferred by many consumers especially in urban areas due to its higher energy density per unit weight, cheaper transport costs and relative cleanness (producing less smoke) than firewood[4••,17••,21], although it emits more carbon monoxide [15•]. Since the 1980s, with urbanization, the share of the energy market taken by charcoal compared to firewood has steadily grown [17••,22].

The potential of woodfuel, particularly charcoal, for economic development is enormous [3•,20]. The charcoal market in SSA provides significant employment and involves many benefiting stakeholders, including collectors, harvesters, producers, transporters, wholesalers and retailers [20]. In 2007, the charcoal industry in the region was estimated to be worth >US$ 8 billion, involving >seven million people in production and delivery. By 2030, the market is predicted to exceed US$ 12 billion, employing 12 million people [3•]. Despite its economic significance, the charcoal market is generally viewed negatively and is often an informal and sometimes illegal business, with a complex and multi-layered regulatory context, which results in an unclear framework for stakeholders [3•,17••,23].

Sustainability of the sector

Firewood supply for domestic use may involve collecting dead wood from non-forest sources [10]. Charcoal production generally relies on cutting of live trees [10,24,25,26••] from natural rather than planted tree stands [2•]. Harvested wood is converted to charcoal in rudimentary earth kilns with an efficiency ranging from 8 to 20% [10,26••].

Displacement for agriculture appears to be the most important driver for deforestation in humid forest areas, with permanent losses of carbon stocks, and charcoal often a byproduct of forest clearance [17••,26••,27]. Production of charcoal, in turn, can have a significant landscape-level impact on land degradation due to multitudes of tree cuttings at production site level even when not driving overall forest cover loss [26••]. With rapid urbanization and population growth in SSA, the negative impacts of charcoal production on forests and woodlands, such as reducing natural regeneration, will increase markedly [4••,17••,25,28].

Options to improve sustainability

Although regarding a complete switch from woodfuels to modern energy as the most desirable intervention, along with other experts [15•], we strongly advocate for improving the sustainability of the existing woodfuel sector as a practical solution, realizing the former will not be feasible in the near future in SSA. To improve sustainability, woodfuel policies need to be harmonized and the efficiency of charcoal production and consumption improved [15•].

Major components of an integrated strategy for a sustainable charcoal industry are improved kilns, improved cooking stoves and sustainable supply in the framework of enabling policies. More efficient kilns will reduce the amount of wood required per unit of charcoal produced, which (all else being equal) should reduce overall wood demand for charcoal production [4••,29••]. Improved cooking stoves that burn charcoal and firewood more efficiently should have the same effect [30], and also reduce air pollution provided stoves are installed and maintained properly [6]. Changes in land management are also required to create sustainable charcoal supply systems rather than the 'one-off' harvesting of wood [29••]. With relevant management, carbon stocks in forests can recover and be maintained along with charcoal production [26••,31].

The changing views and approaches to address the woodfuel problem

Low adoption of agroforestry for charcoal production

Agroforestry may play an important role in making charcoal supply more sustainable by reducing pressure on harvesting wood from natural tree stands through increasing wood supply on farm.[b] To date, however, adoption rates of agroforestry practices especially focused for charcoal production in SSA and elsewhere are in general disappointing [22,24]. It is worth learning from the past approaches for the failure.

Lessons from earlier approaches

In the 1970s, the woodfuel crisis was a hot issue not only for Africa but for Asia. The common approach then was a so-called a supply-demand gap theory. Projecting the demand for woodfuels excessive of the supply capacity of forests, it generally advocated massive aforestation and reforestation to close a widening gap, especially targeting high agricultural potential zones whose forests were perceived most threatened by local woodfuel demand driven by high

[b] On-farm production of resources can also result in market and infrastructure development that 'pulls in' wild resources as well as planted stock, and which result in forest clearance for further planting and the relegation of natural stands to 'stop-gap' supplies [32].

population density [33,34]. By the late 1980s, however, the gap approach turned out to be not effective in achieving the desired outcomes [34,35]. Recommended woodlot for woodfuel supply was not undertaken by farm households who were instead interested in planting trees for commercial poles/timbers which fetched higher unit values [34,36,37]. Indeed, detailed studies revealed that farms in high potential areas frequently had sufficient tree covers thus abundant woody biomass, yet women had reported increasing difficulty in obtaining domestic supplies of woodfuels [35,38–40].

The failure of the gap approach called for placing woodfuels within the wider context of local faming systems and social and economic environments [35,37]. Dewees [41••] critically argued that the gap approach only focused physical scarcity of woodfuels, and ignored the economic scarcity, that is, farm households' cost and time to obtain woodfuels in a dynamically changing society. Even if wood becomes physically scarce, as long as labour is abundant — the lack of economic scarcity, woodfuel supply remains cheap. In turn, woodfuel supply becomes problematic even without the physical scarcity of trees. For example, in high potential areas opportunity costs of labour are high due to the presence of economically attractive enterprises, or migration makes labour chronically scarce. In such a situation, farm households' reaction includes either managing multi-purpose trees on farm to save labour to collect woodfuels, or purchasing woodfuels while specialized in on-farm/off-farm enterprises.

Factors masking the magnitude of the problem

After the counter-arguments, many woodfuel related projects were scaled down by the 1990s [22]. A prevalent view was that the widely predicted woodfuel crisis, with rising prices for urban consumers, has not taken place at the scale predicted. In India, for example, despite the population growth and urbanization, the quantities of woodfuels used by households fell drastically due to huge shift in the choice of household cooking fuels to fossil fuel [24,34]. In contrast, in SSA, the importance of woodfuels, especially charcoal, has grown since the 1980s [22], while drylands have emerged as major charcoal supply areas to urban areas. For example, roughly 75% of all the charcoal utilized in Kenya is considered to come from the drylands [42].

Interestingly, the charcoal supply in SSA has been regarded highly 'efficient' at meeting demand in the word of some experts [17••] while anecdotal evidences indicate the shifting of charcoal 'hotspots', often into drier conditions [43], accompanied by extensive degradation leading to downgrading of woodland to bush, and bush to scrub, over very large areas [24]. The apparent lack of crisis could be explained by the lack of economic scarcity in the context of drylands where opportunity costs of labour remain relatively low due to the lack of alternative economic opportunities due to low agricultural and market potentials, while infrastructure development may keep transport costs from rising as hotspots shift into further hinterlands.

Projecting the impacts of charcoal demand under different intervention scenarios

Data and methodologies

There is lack of reliable data and consistent methodologies to assess the magnitude of the impacts of charcoal demand-supply on tree covers in SSA. National estimates on charcoal consumption levels tend to be higher than the charcoal demand reported by FAO[c] [2•,17••,29••]. On the other hand, there is a tendency that national figures of deforestation reported by FAO statistics are higher than the estimates derived from high resolution satellite images [45–47]. The latter analyses also reported the magnitude of forest degradation but did not present how much of it was driven by wood demand for charcoal against agricultural land expansion [47]. Therefore, though being one of the most extensive coverage on the woodfuels, FAO data may tend to underestimate charcoal demand compared to country surveys on one hand, and overestimate deforestation trends compared to satellite data analyses on the other hand.

A few studies have tried to estimate and/or project the impacts of charcoal demand on tree covers, by converting wood required to produce charcoal into forest/woodland areas, principally using the following formula:

$$\text{the area needed to meet wood demand for charcoal(ha)} = \frac{\text{the volume of wood demand for charcoal(tonne) with different kiln\& stove efficiencies}}{\text{biomass stock rate(tonne/ha) with or without agroforestry}}$$

The biomass stock rates $_{year}$, defined as (biomass stock $[\text{tonne}]_{year}$/forest area $[\text{ha}]_{year}$), vary considerably between time and across SSA countries, even within a country, with humid regions having higher stocking rates than drier regions. FAO's WISDOM (Woodfuel Integrated Supply/Demand Overview Mapping) project [48] has attempted to develop a dynamic spatial model and applied it to selected eastern African countries. It uses biomass stock rates across all the landscape categories derived from FAO's LANDCOVER maps to estimate supply in terms of land areas. But for most SSA countries, charcoal demand estimates are often only available at national-scale, while biomass stock rates are available for forest areas only and often reported for a national average. In applying the formula to the forest

[c] For example, Kenyan national charcoal survey estimated 1.6 million tons of charcoal in 2004 [44] and 2.5 million tons in 2013 [43], while that of FAOSTAT showed 640,501 in 2000, and 16,500–17,700 t/year for 2001–2011.

biomass stock, Chidumayo and Gumbo [26••] noted the possibilities of overestimating the impact of charcoal demand on forest covers as charcoal is rather a by-product of agricultural land expansion. Acknowledging the problem, they used the FAO data, and concluded that charcoal-induced deforestation contributes to a fraction of the total forest cover loss reported in Africa ($14 \pm 5\%$) and in the tropical countries on average ($7 \pm 2\%$) [26••]. Interestingly, using a similar formula with different data and assumptions would lead to contrasting conclusions. For example, Mwampamba [49] extrapolated urban charcoal demand in Tanzania derived from the 244 household data under different scenarios of kiln efficiencies and biomass stock rates, and predicted forests would deplete in next few decades in extreme scenarios.

Assumptions

Acknowledging the constraints, we use FAO data and the formula above to make tentative projections of the impacts of the adoption of improved kilns, improved cooking stoves and agroforestry as an integrated sustainable charcoal strategy on tree covers to guide policy debates. The rationales behind key assumptions are given below.

In African drylands, hard-wood tree species such as *Acacia* spp. are considered to produce a good quality charcoal [50]. Commonly, trees with diameters >4 cm can be used for charcoal production, while the remainder is used as fuel for kilns, kiln spacers, and firewood (<2 cm diameter) [51]. The efficiency or recovery rate of charcoal kilns depends on the kiln specifications and skills to control carbonization processes to minimize unnecessary combustion of wood that would have otherwise been carbonized. Table 1 summarizes the specifications of different charcoal kiln types. Retort kilns with carbonization chambers can achieve the yield of 30–40% while half orange kilns also present high recovery rates of 25–35% [52]. They present a potential compatibility with simple tree management such as coppicing and agroforestry practices with shrubs as small branches and twigs can be carbonized rather than mature large stems. But high investment requirement, limited field experiences (Adam retort, meko) and no durability (half orange) may prevent the uptakes by poor charcoal producers in the near future. In turn, earth kilns, whose rudimentary forms are currently most adopted in SSA, have also potentials to improve their recovery rates from 10% to 30% with relatively low investment costs (in metal nets or sheets/chimneys), while requiring skills for stack arrangement in precision [42,52,53]. In our model, a scenario with a constant kiln efficiency of 10% are compared with a scenario with a gradual improvement of kiln efficiency from 10% at the base year of 2015 to 30% by 2050 assuming a gradual dissemination of improved technologies.

One of the main motivations for improved cookstove interventions has been to reduce household demand for woodfuel thus to reduce pressures on deforestation [30,54]. Improved cooking stoves potentially reduce average daily per capita fuel use by 19–67%, but the outcomes vary depending on the operating conditions [30]. A recent study in turn reported kitchen performance tests in rural Kenya, where the use of rocket mud stoves in place of traditional three-stone stoves reduced daily fuel uses by 19% (from 6.7 kg/day to 5.4 kg/day, a cross-sectional result) and by 29% (from 6.5 kg/day to 4.6 kg/day, a longitudinal result) [55]. Based on it, our model assumes that a gradual uptake of improved cookstoves by households will reduce the wood demand by 20% between 2015 and 2050.

Very few studies are available on wood yields of agroforestry systems under smallholder conditions in SSA. In turn, there are some experimental studies on woodfuel yields on multi-purpose agroforestry systems, for example, different species of *Leucaena*, *Crotalaria*, *Tephrosia*, as well as *Sesbania sesban*, *Caliandra calothyrsus*, *Alnus acuminata* in humid/sub-humid conditions [56–58] and different species of *Acacia*, *Leucaena*, and *Gliricidia sepium* in semi-arid conditions [36,59]. Experimental studies from Tanzanian drylands reported that rotational woodlot systems using fast growing N_2-fixing tree species have the potential to produce 20–50 t/ha of wood in five years [36,59]. Their mean annual increment (MAI) of 4–10 t/ha/year are far higher than reported MAIs of natural or minimally managed vegetation: 2.8 t/ha/year (calculated from the reported carbon stock of 1.4 t/ha/year) after land clearance for charcoal in Miombo dry forests in Zambia with 1,200 mm rainfall per annum [31]; 0.04–2.9 t/ha/year of wood from natural Miombo vegetation in Mozambique [59], and 1.3 t/ha/year estimated for indigenous acacia species under a 14-year coppicing stands in arid Laikipia in Kenya with 500–550 mm annual rainfall [51]. At the same time, while charcoal production with conventional earth kilns requires wood with diameters >4 cm [51], rotational woodlot systems can produce wood with 4–15 cm diameter at breast height (DBH) in five years [36,59].

For our model, we assume that the adoption of producing woodfuel on farm reduces the pressure of harvesting wood in forests, thus reduce the rate of biomass stock change in forests. The biomass stock change between 2000 and 2010 was estimated for each country using the FAOSTAT FRA 2010.[d] They were then divided by 10 to derive a mean annual biomass stock change rate for the scenario without agroforestry on one hand, and on the other hand divided by 30 to derive a reduced rate of

[d] In FAOSTAT FRA2010, the data for growing stock [the volume, m^3] and carbon stock [the weight, tonne] was reported for each country's forest area, while the data for biomass stock [the weight, tonne] was not reported unlike FRA2005. Relatively more consistent data for SSA countries between FRA 2005 and FRA 2010 was available in terms of carbon stock than growing stock, thus the carbon stock data was used to estimate the biomass stock using a factor of 2 (FRA estimates carbon in living biomass as 50% of biomass stock figures).

Table 1

Comparison of charcoal kiln specifications.

Kiln type		Recovery rate	Wood size	Notes on scales/skills/ investment
Earth	Pit kiln	11.8% (a)	–	The pit kiln is more commonly used in Asia. America (a)
	Traditional earth mound kiln	8–10% (c)–15–20% (b)–20–30% (d)	Wood chopped into sizeable pieces (b)	No need of transport as to construct close to the wood supply site, are flexible in size and shape, well-matched to the dispersed nature of the charcoal trade, little capital yet, requires skill to achieve high efficiency (b), (d), (e), (f)
	Improved earth kiln	25.7% (a)–27% (e)	Workable pieces, 1–1.5 m (e)	
	Casamance kiln	16.8% (a) to 26–30% (e)	0.5 m length wood with different diameters, mainly larger pieces (e)	
Masonry	Dome kiln	28–30% (b)	Tree stumps (b)	Immobile, transport costly (b)
	Half orange kiln	25–35% (g) (50–60% (b)*)	Twigs and branches (b)	Uses small materials (b)
Metal	Drum kiln	28–30% (e)–32–38% (f)	Stems or tree branches of 6–10 cm diameter with 80 cm length (e)	Suitable for household domestic production (e)
	Portable steel kiln	About 25–30% (e)	A max diameter of 20 cm, 45–60 cm long (e)	Designed to be easily transported, high capital costs (e)
	Meko (Mekko) kiln	(50–75% (b)*)	1.5 cm diameter (b), 0.8 m long pieces (e)	Consisting of two chambers — the inner, basically a modified drum, for carbonization and the outer for firing, designed to cause pyrolysis of dry wood to take place in an inner chamber to facilitate complete carbonization. Easy to assemble, mobile, but still prototype/costly (b)
Retort	Adam retort kiln	30–40% (g)	Can utilize branches of shrubs and small trees such as *Tarconanthus camphorates* (b)	The kiln returns the wood gases and heat back to the carbonisation chamber, burns a higher proportion of the tar components, leading to higher efficiency and reduced noxious emissions. High investment costs, suitable for semi-industrial/industrial use, yet limited field experience (g)

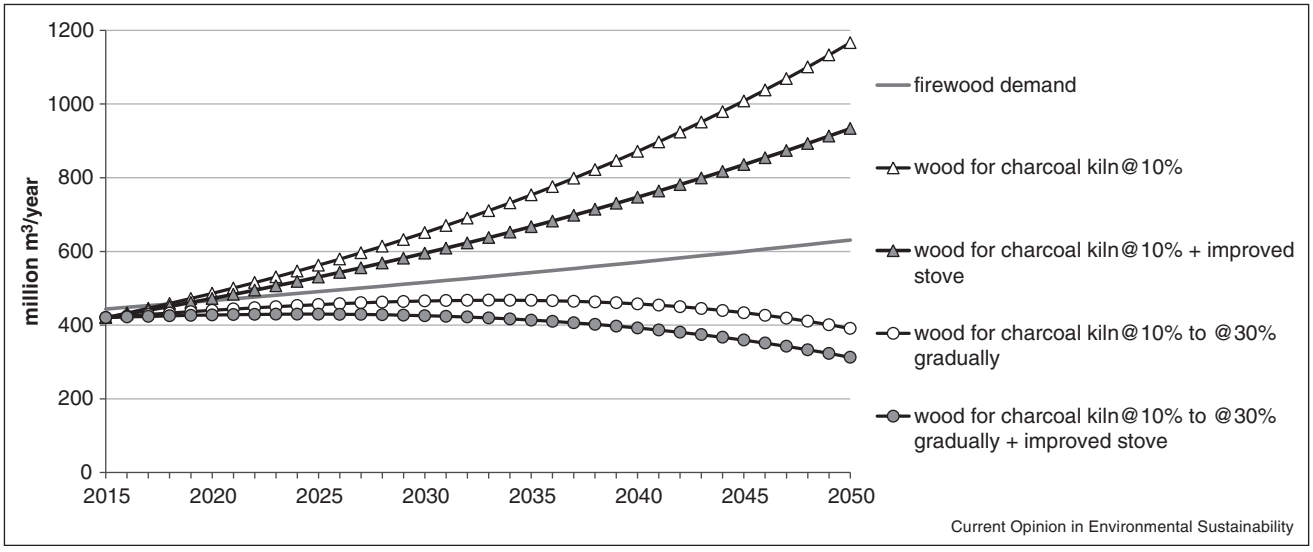
Source: (a) Chidumayo and Gumbo 2013 [26]; (b) Kalenda et al. [42]* (these figures on half orange kilns and meko kilns can be overestimated, as normally it is not possible to get recovery rates of more than 50% from wood carbonization); (c) ESDA [44]; (d) Bailis 2009 [29]; (e) Oduor et al. 2006 [53]; (f) Oduor et al. 2012 [50]; (g) Vis 2013 [52].

annual mean biomass stock change under the agroforestry scenario. Then we used the derived ''annual'' biomass stock change rates for each country to project levels of biomass stock annually for the period from 2015 to 2050, respectively for the scenarios without or with agroforestry. Under the agroforestry scenario, the biomass stock rate in forests could improve by 0.65 t/ha/year, compared to 0.19 t/ha/year under the scenario without agroforestry, on average for all the SSA countries in the same period. Variously reported wood productivity of MAI of 4–10 t/ha/year in agroforestry systems is far larger than this assumed biomass stock change rate in forests under the agroforestry scenario (0.65 t/ha/year on average), thus it may be a rather conservative assumption.

Projections of wood demand for charcoal

The average annual growth rates of charcoal consumption in SSA between 2000 and 2010 were 1.01% for firewood and 2.96% for charcoal, and the latter was higher than the average population growth rate of 2.58% of the same period. Using these incremental increases to project the

Figure 3



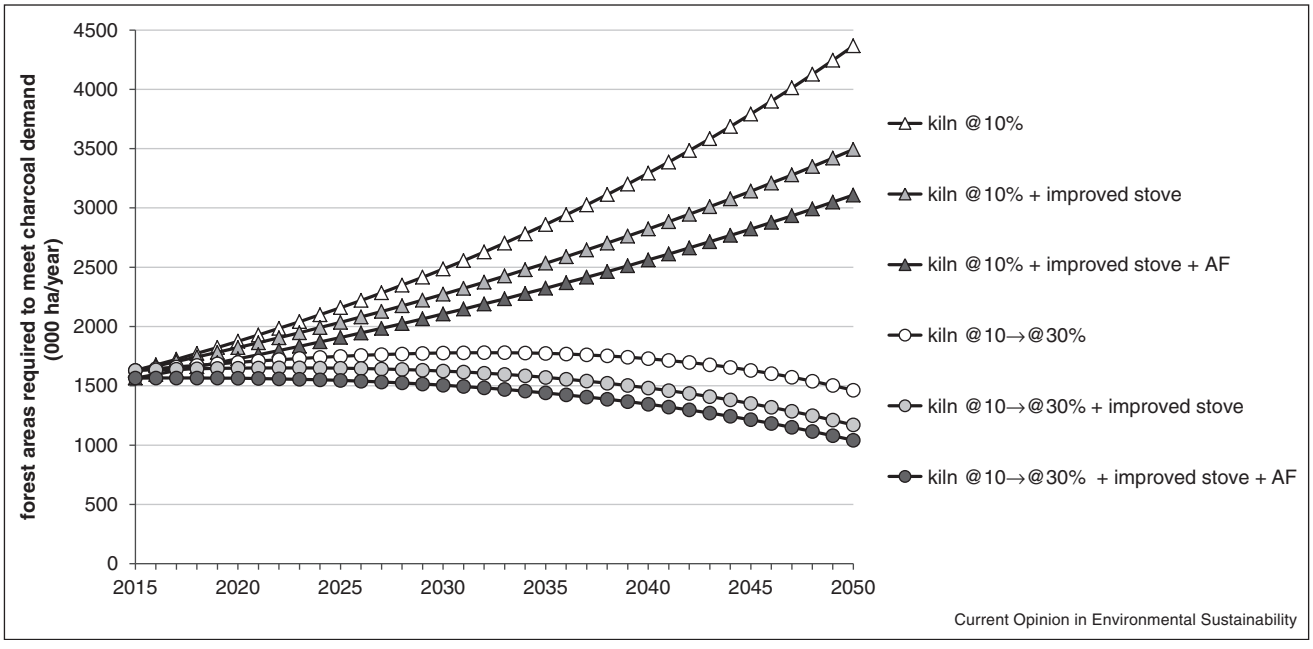
Projected woodfuel demand under different kiln and stove efficiency scenarios in sub-Saharan Africa. Notes: Where there were obvious reporting errors on charcoal demand in FAOSTAT for individual countries, figures were adjusted when other national data on consumption were available.

future trend, the demand for charcoal will increase by 2.8 times and that for firewood by 1.4 times between 2015 and 2050. Projections of wood demand for charcoal and firewood under different kiln and stove efficiency scenarios are given in Figure 3. A gradual improvement in kiln efficiency from 10% to 30% would result in massive savings in wood requirements. The gradual adoption of charcoal cooking stoves with an improvement in efficiency of 20% would also result in significant savings.

Impacts of wood demand for charcoal on tree cover and a potential role of agroforestry

Figure 4 integrates the impacts of kiln/stove efficiencies on wood demand and the impacts of agroforestry adoption

Figure 4



Projected areas of natural forested and woodlands cut to meet charcoal requirement in sub-Saharan Africa based on different intervention scenarios. *Notes*: Data are based on the same countries as in this figure, except Djibouti, Eritoria, Mauritania, Sudan (former) and Togo.

on maintaining biomass/carbon stock in the forests to present their combined impacts on tree cover. The scenarios with an inefficient kiln present an alarming picture. For example, the land area estimated to be required to meet the charcoal demand in the base year of 2015 under all the scenarios was about 1.6 million ha, over the half (58%) of the forest areas to be lost during 2014–2015. Under the scenario with 10% kiln efficiencies without improved stoves and agroforestry (all else being equal), by 2050, 4.4 million ha of forests will be annually needed to meet wood demand for charcoal. The forest areas under pressures can be even larger, if the real charcoal consumption could be larger than the FAO estimates used here [2•]. In contrast, the gradual adoption of improved kilns together with improved cooking stoves and agroforestry can greatly reduce pressures on forests, as the forest areas required annually in 2050 could be even less than those at the base year (2015) level.

Conclusions

There can be serious dryland forest/woodland degradation ongoing and projected under business-as-usual scenarios, although the lack of quality data and consistent methodologies have prevented from assessing the magnitude of the environmental and socio-economic impacts of increasing wood demand for charcoal production. A recent report [2•], alarming the projected situation in Africa, called for an urgent supply-side intervention. Especially, agroforestry, if widely adopted at landscape level as an integrated strategy together with the promotion of improved kilns and stoves, can have a significant impact to reduce wood harvest pressures in forests and woodlands through sustainably supplying trees on farm. These will support climate change mitigation and adaption in the SSA region through sequestering carbon and promoting resilience [8,60].

The past experiences and current dryland socio-economic contexts, however, remind us of the need for a systematic approach to promote multi-purpose agroforestry systems compatible with farmers' needs in the context of local farming systems, rather than giving a singular focused approach on woodfuel provision. Some technologies are promising, for example, rotational woodlots using fast growing and N_2-fixing tree species can not only provide quality woods for charcoal but also offer twigs and branches as foliage for livestock. At the same time they allow farmers to intercrop without sacrificing yields of food crops in the first 2 years, and improving their yields following wood harvest [36,59]. To promote these technologies, more research is needed to match right tree species to right environment, that is, agroecology, soil conditions. For, tree growth in terms of height and diameter required for conventional charcoal kilns can differ among different tree species due to the difference in the adaptation capacity in any particular environment [36]. In the meantime, it is also critical to promote innovations to develop affordable and acceptable kiln technologies which will make full use of wood resources [42,51].

Key information gaps that need to be addressed to better support a woodfuel policy in the region include:

- a better understanding of future demands for different energy sources in SSA and the possibility of transformational changes in energy supply.
- comparative data on wood yields in farm and forest environments and the possible gains through different agroforestry options (tree species, management) across different agro-ecological zones.
- greater knowledge on the factors affecting the current limited adoption of improved kilns, improved cooking stoves as well as agroforestry practices. For the latter, a consideration of options to encourage farmers to increase their supply of woodfuels as a co-product or bi-product of their strategies for incorporating and managing on-farm trees and shrubs for purposes such as fodders, timbers, soil fertility.
- best enabling policy environments for sustainable charcoal.

Acknowledgements

This work benefitted from the financial support of Japanese Government which contributed to the lead author's engagement in bioenergy-related projects at World Agroforestry Centre (ICRAF). Our special thanks go to Ian Dawson for reviewing and editing this manuscript. We sincerely appreciate the two anonymous reviewers who provided truly valuable comments to improve the manuscript.

References and recommended reading

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- • of special interest
- •• of outstanding interest

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This report presents a projection of wood demand for firewood, charcoal as well as industrial roundwood in Africa, similar to ours, and warns that wood demand will surplus sustainable supply, thus deficit will be compensated by unsustainable supply and import, with negative implications for African development.

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